Formation, distribution, and nature of *Picea mongolica* in China

ZOU Chun-jing, HAN Shi-jie, XU Wen-duo
(Institute of Applied Ecology, Chinese Academy of Sciences, Shenyang 110015, P.R. China)

SU Bao-ling
(Biological and Environmental Engineering College, Shenyang University, Shenyang 110044, P.R. China)

Abstract: *Picea mongolica* is an endemic and endangered species in China. Ecosystem made of *Picea mongolica* is a special sandy forest ecosystem in China. It is found at ecotone between forest and steppe, or agricultural district and pastoral area. Based on investigation, this paper discussed the formation and distribution of *Picea mongolica* and studied its nature according to ecotone theory. It is clarified that *Picea mongolica* belongs to *Picea meyeri* series. That is to say, it became a local race through long-term adaptation to the local climate, then formed allopatric semi-species, and finally turned into a taxonomical species. *Picea mongolica* forest is a super zonal climax community developing in ecotone between forest zone and steppe zone.

Key words: *Picea mongolica*; Formation, Distribution; Nature; Sandy forest; Ecotone
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Introduction

Picea mongolica is an endemic and endanger species in Inner Mongolia, China (Xu & Zou, 1998). The ecosystem made of *Picea mongolica* is a special forest ecosystem type because it is a sandy forest type, and it is found at the ecotone between typical forest and steppe (Zou *et al.* 1999). As far as cultivation way is concerned, the forest is in ecotone between agricultural district and pastoral area. The area is also transition zone from Daxing'an Mountains to Hunshandake Desert.

Many researches have been carried out on ecotone community or ecosystem between forest and steppe (Bowman, 1992; Dyer & Baird 1997; Guo 2001). It has been suggested that ecotone support relatively high biodiversity and produce more primary production. So biodiversity and primary productivity in ecotone are very important research contents about ecotone. In recent years, many ecologists made studies on community development and dynamics (Carter *et al.* 1994; Fortin 1994; Stohlgren & Bachand 1997; Tsuchiya *et al.* 1993).

Study area and method

Baiyinaobao Natural Reserve was chosen as the study area, which is located at 43°30'-43°36' N latitude, 117°06'-117°16' E longitude, with an altitude range of 1300-1500 m. The natural reserve covers a land area of about 6737 hm^2 and it is a part of Hunshandake Desert (Zou *et al.* 1999). *Picea mongolica* is only found here naturally. Sandy land, hillside, riverbank, and meadow distribute in the reserve and the windy sandy land as a main body spread from northwest of the reserve to southeast. Its formation has relationship with climate drought in the end of the Quaternary Period (Xu & Zou 1998). The highest mount is Aobao hill, with an altitude of 1498.8 m, composed by volcanic lapillus and basalt. The other place is covered by sand, and the thickest layer of sand is about 100 m.

Climate here is a typical temperate continent steppe climate, characterized by rigid cold and long in winter, windy and drought in spring, warm and short in summer, and changeable in autumn. Annual mean temperature is -1.4°C, and mean temperature is -23.4°C in January and 14.7°C in July. Accumulated temperature of >5°C in one year is 1942 °C. Annual precipitation is 448.9 mm, and mainly distributes from June to August, taking up 68% of that of the whole year. The frost-free period is 65 days. Zonal soils of this area are mainly black soil and brown soil, which distribute dunes. Generally speaking, formation of soil has relationship with vegetation, especially with forest. In Baiyinaobao Natural Preserve, sandy gray soil under *Betula platyphylla, Populus davidiana,* and *Picea mongolica* forest is main soil types, and its physical composition and chemical characteristics are shown in Table 1 and Table 2.

The study methods include data collection and field investigation.

Results

Formation of *Picea mongolica* in China

Picea mongolica forms by the way of gradual speciation.

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Biography: ZOU Chun-jing (1968-), male, Ph.D, associate researcher fellow in Institute of Applied Ecology, Chinese Academy of Science, Shenyang 110015, P. R. China
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According to Darwin's theory of species evolution, formation of a new species is firstly originated from geographical or spatial isolation, then produces reproductive isolation, and finally leads to differentiation of group and new species. However, gradual speciation needs a very long time, and it can't repeat in short term. Then, how does *Picea mongolica* form?

Table 1. Physical composition of sandy gray forest soil

Depth	Pellet composition (%)				Diameter of pellet (%)			
(cm)	>1.0	1.0-0.25	0.25-0.05	0.05-0.01	>0.01	0.01-0.005	0.005-0.001	<0.001
7-8	-	6.0	63.9	15.0	84.9	4.5	2.5	8.1
20-30	9.8	59.7	36.7	1.2	97.6	0.2	1.2	1.0
60-70	8.7	61.6	35.3	0.8	97.3	2.3	-	-

Table 2. Chemical characteristics of sandy gray forest soil

Depth	pH	Humus		Exchangeable cation				Base content	Saturation degree	Whole N	P_2O_3
/cm		N_2O	KCl(%)	Ca^{2+}	Mg^{2+}	H^+	Al^{3+}	(mg/100g)	(%)	(%)	(%)
0-7	5.9	5.2	-	-	-	-	-	-	-	-	-
7-18	6.1	5.5	0.86	31.03	2.86	-	0.06	33.89	88.79	0.59	0.11
20-30	6.2	5.5	0.76	3.76	4.76	-	0.03	8.52	92.60	0.24	-
60-70	6.3	5.7	0.12	5.21	4.82	-	-	10.03	96.35	-	-

Based on research of paleobotany, it is well known that *Picea* spp originated from the Northern Hemisphere. Their fossils are found existing in Jurrasic Period, and it has 160-190 million years history. In China, fossils of *Picea* spp are found before the Pleistocene Epoch in Taigu, Shanxi Province and the Tertiery Period in Litang, Sichuan Province. *Picea* spp originated from tropical mountains, and Hengduan Mountains in Southwest China are the critical district. According to the hypothesis, we could show the formation process of *Picea mongolica* (*Xu et al.* 1998).

It is well known to all that modern distribution of any species is not only an eco-geographical phenomenon, but also continuity of historical distribution. We thought that *Picea mongolica* was relative species of *Picea meyeri*, and then evolved into a new species based on eco-geographical distribution, development of speciation, morphological character, and differentiation of molecule. It proved that by research on fossil and pollen of plant, climate in Northeast China and Inner Mongolia Autonomous Region during the middle of the Tertiery Period was similar with that of Changjiang River watershed in modern time, and it belonged to warm and wet north subtropical climate. Under such climatic conditions, dark coniferous forest (*Picea-Abies* spp forest) distributed extensively. *Picea* spp could extend to Northeast Plain and North China Plain. *Picea meyeri* distributed from Shanxi Province to eastern area of Inner Mongolia Autonomous Region, China. However, in the end of the Tertiery Period, especially during the Quaternary Period, the alternative change of Glacial Epoch and Interglacial Stage led to climate change regularly, which has deep effects on distribution, succession, dynamics, and regeneration of species in boreal plant communities in China (Fig. 1).

In cold period, the dominant vegetation was dark coniferous forest, then steppe vegetation, and finally dark coniferous forest due to glacier activities; and during warm period, superior vegetation was coniferous broad-leaved mixed forest, then broad-leaved forest, and finally coniferous broad-leaved mixed forest.

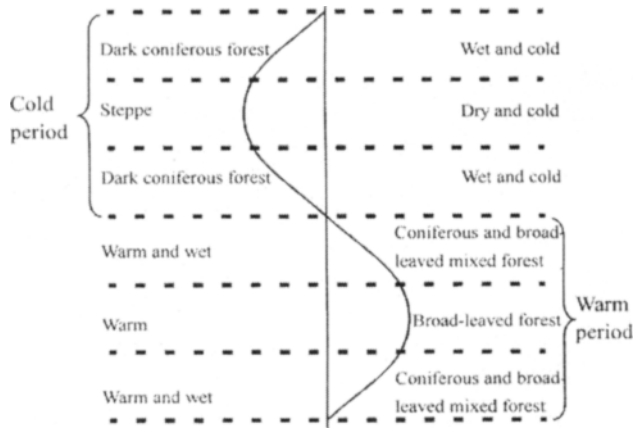

Fig. 1 Relationship between climate change and vegetation succession in the Quaternary Period in northern area of China

Before 30 000 to 24 000 years, in most area of China, *Picea* spp distributed most extensively because of cold and wet climate impacted by global decreasing of temperature. After that period, it was cold and drought in China, especially in eastern steppe area in Inner Mongolia Autonomous Region. *Picea meyeri* could not adapt to cold and drought climate, and moved upwards adaptive mountains nearby, for example, Daxing'an Mountains, North China Mountains, and so on. However, *Picea meyeri* still stayed at Inner Mongolia Plateau, partly died of natural selection and species competition, and part of them developed a slow differentiation process by changing and

consummating their structure and function. Firstly, they became adaptive species-local race, then developed into allopartric semi-species, and finally formed taxonomical species (Xu & Zou 1998).

Distribution of *Picea mongolica* in China

According to Kira's warmth index and coldness index, Xu Wenduo proposed Xu's humidity index, *HI=P/WI*. Where *HI* is humidity index, *P* is annual precipitation of a certain place, and *WI* is warmth index.

Vegetation distribution has a close relationship with humidity index (Table 3). Generally, humidity index of *Picea* spp are from 7.10 (*Picea mongolica*), 9.72 (*Picea meyeri*) to 10.75 (*Picea koraiensis*) based on our studies.

Table 3. Relationship between Xu Wenduo's humidity index (HI) and vegetation

Humidity Index (mm/(℃ • month)		Climate type	Vegetation type
HI	>15.5	Extremely humid area	Cold-wet vegetation
HI	15.5-7.5	Humid area	Forest
HI	7.5-5.5	Semi-humid area	Forest steppe
HI	5.5-3.5	Semi-arid area	Typical steppe
HI	3.5-1.5	Arid area	Desertion steppe
HI	<1.5	Extremely arid area	Desert

Generally speaking, *Picea* spp forest is pure or mixed forest composed of *Picea* spp. However, *Abies* spp always grow in *Picea* spp forest because of its biological characters. The mixed forest is evergreen, dark, and wet, so it is called dark coniferous forest by ecologists.

Picea spp forest only distribute in the Northern Hemisphere. The northern border is about 70° N in latitude; and the southern border is about 21° N in latitude in Huanglian Mountains in Vietnam. From 57°N to north, *Picea* spp forest is zonal vegetation. But it is vertical zonal vegetation southwards from the border. In China, *Picea* spp forest distribute mainly in the mountains of Northeast China, North China, and Southwest China.

In North China, *Picea* spp forest is mainly composed of *Picea wilsonii, Picea meyeri*, and other coniferous and deciduous tree, such as *Larix priucipis-rupprechtii, Betula platyphylla, Betula davurica, Betula albo-sinensis, Sorbus pohuashanensis*, and so on.

Picea spp forest in Northeast China is part of northern Taiga forest. The edificators are *Picea koraiensis, Picea jezoensis, Abies nephrolepis* and so on. It is typical dark coniferous forest. Temperature is limiting factor on its growth and development. It distributes in mountains regularly. For example, it distributes from 1 100 to 1 700 m altitude in Changbai Mountains, from 900 to 1500 m altitude in Zhangguangcai Mountains, and from 700 to 1 100 m altitude in Xiaoxing'an Mountains. However, their warmth index is basically unique (20-45℃ • month), although their location and elevation are different from each other (Fig. 2).

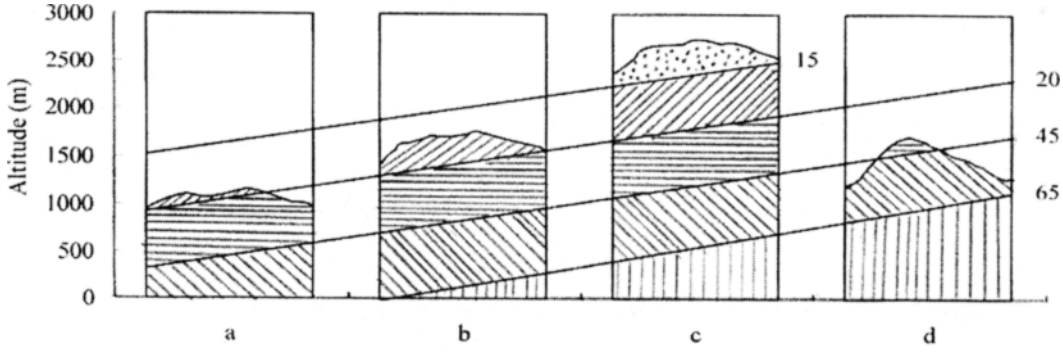

Fig. 2. Relationship between vegetation vertical distribution and warmth index in Northeast China

a. Gaotai Mountains (1 160 m, 46°48′N). b. Datudingzi Mountains (1 760 m, 44°40′ N). c. Changbai Mountain (2 691 m, 41°59′ N). d. Baishilazi Mountains (1 232 m, 40°50′N). Vegetation types from top to bottom are alpine tundra, *Betula ermanni* forest, *Picea--Abies* forest, *Betula davurica--Fraxinus mandshurica--Pinus koraiensis* mixed forest, and *Abies holophylla--Carpinus cordata--Pinus koraiensis* mixed forest.

Nature of *Picea mongolica* forest in China

In order to describe nature of *Picea mongolica* forest, we introduced "super zonal climax" concept (Liu 1985). Cox considered old-growth forests as ultra-climax ecosystems, and he thought that old-growth forests were "mature" forest stands (Cox 1993). This concept is different from "super zonal climax", and similar with Liu Shene's "post-climax" (Liu 1985). Generally speaking, zonal climax is controlled by climate, and zonal climax is conformed to local climate. Furthermore, there is only one type zonal climax in one certain climate area. "Super zonal climax" is stable community adapting to its ecological environment.

The community has zonal brand during different eco-processes, and there is only progressive succession series. We could understand the concept from the following two aspects.

(1) As far as macroscopic geographical distribution of *Picea mongolica* forest is concerned, its elevation is about 1 600 m. Though there is no vertical vegetation zonation in Baiyinaobao, there is certain vertical differentiation. From 700 to 900 m, the vegetation type is typical zonal steppe, and the edificator is *Stipa grandis*, also there are some composition of steppe, such as *Leontopodium leontopodiodes, Cymbaria dahurica, Potentila bifurca, Iris tenuifolia, Allium anisopodium* and so on. From 1 000 to 1200 m, the vegetation types are *Stipa baicalensis* steppe and *Filifolium sibiricum* steppe, and there are some other species, for example, *Sanguisorba officinalis, Vicia* spp, *Trifolium lupinaster*, and *Galium verum*. From 1 300 to 1500 m, the vegetation type is *Picea mongolica* forest, and there are some species, such as tree species (*Betula platyphylla, Populus davidiana*) and herb species (*Koeleria cristata*) and so on. Obviously, *Picea mongolica* forest exists in the typical sandy forest-steppe ecotone, so it is a super zonal climax vegetation adapting to local climate (Fig. 3).

(2) The formation process of *Picea mongolica* forest is conformed to the fixation process of dunes, and it has deep zonation brand. Generally, the extent of dunes fixation develops with vegetation succession in sandy forest-steppe ecotone (Table 4).

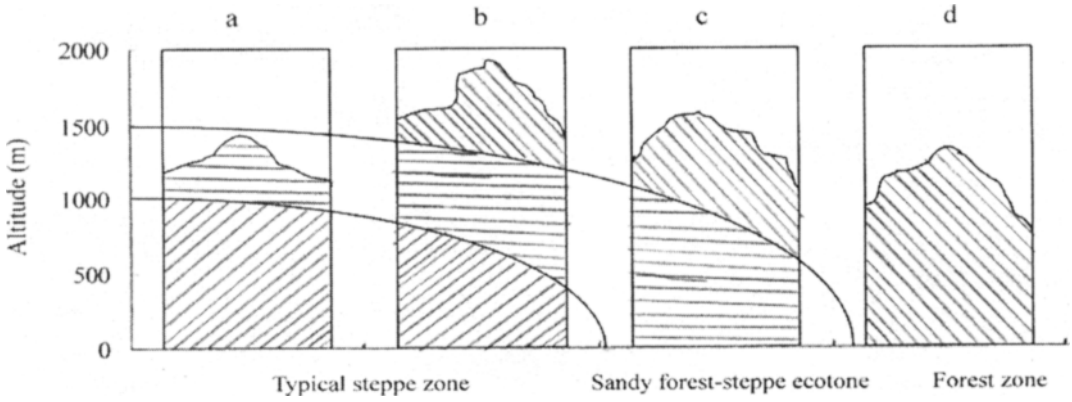

Fig. 3. Relationship between forest and steppe in horizontal and vertical zonation at Daxing'an Mountains

a. Baiyinaobao (southern part of Daxing'an Mountains). b. Huanggangliang Mountains (southern part of Daxing'an Mountains). c. Aer Mountains (middle part of Daxing'an Mountains). d. Baikalu Mountains (northern part of Daxing'an Mountains).

Table 4. Vegetation succession stages in sandy forest-steppe ecotone

Dunes type	Steppe zone	Forest steppe zone
Flowing dunes	*Sasola ruthenica, Crispermum* spp pioneer association	*Salsola ruthenica, Crispermum* spp pioneer association
Semi-stable dunes	*Artemisia frigida* association, *Artemisia desertorum* association	*Artemisia desertorum, Polygonum divaricatum* association
Stable dunes	*Cleistogenes epigeios* steppe, *Agropyron cristatum* steppe, *Caragana microphylla* shrub, *Ulmus pumila* sparse forest	*Filifolium sibiricum* steppe, *Poa pratensis* herb steppe, *Rosa davurica* shrub, *Ostryopsis davidiana* shrub, *Betula platyphylla* forest, *Populus davidiana* forest, *Picea mongolica* forest

Discussion

Owing to special natural historical causes and extensive human activities, there happened many changes in northern area of China. Natural forest distinguished rapidly in sandy land. However, there exist some forests in sandy land for special habitats. These forests exist in ecotone between forest zone and steppe zone, ecotone between steppe area and desert, and ecotone between riverbank and mountains (Zou 2000). For example, *Pinus syvestris* var. *mongolica* forest lies in Hulunbeier Sand in northeastern part of Inner Mongolia Autonomous Region, sandy broad-leaved forest in Daqinggou Natural Reserve, Keerqin Sand, Inner Mongolia, *Picea mongolica* forest in Hunshandake Sand, *Ulmus pumila* sparse forest in Keerqin sand, *Pinus tabulaeformis* forest in western area of Liaoning Province. *Haloxylon* spp forest in Maowusu

Sand and Badanjilin Desert in the middle area of Inner Mongolia, *Populus euphratica* forest in Talimu River bank of Xijiang Weiwuer Autonomous Region, China. Sandy forest in China is natural forest asset, which is deserved to protect. So it is urgent assignment to develop research on sandy forest (Xu *et al.* 1998; Xu & Zou 1998).

It is well known that vegetation distribution is affected by many factors. For example, natural historical causes, human activities, and so on. Among them, climate is very important. Zonal vegetation is conformed to local climate, and it can develop succession and leads to zonal climax. However, in zonal vegetation, there exist non-zonal climax due to special habitat and microclimate, such as swamp (Liu 1985). But some vegetation called "super zonal climax", such as *Picea mongolica* forest, has zonal brand, and develops only progressive succession series, finally forms a stable climax vegetation adapting to local climate. Super zonal climax is different from ultra zonal climax, which is cited by Cox in his works.

References

Bowman, D.M. 1992. Monsoon forests in north-western Australia. II. Forest-savanna transitions [J]. Australian Journal of Botany, **40**: 89-102.

Carter, V., Gammon, P.T., Garrett, M.K. 1994. Ecotone dynamics and boundary determination in the Great Dismal Swamp [J]. Ecological Applications, **4**: 189-203.

Cox, G.W. 1993. Conservation ecology: biosphere and biosurvival [M]. Wm. C. Brown Publishers.

Dyer, J.M., Baird, P.R. 1997. Wind disturbance in remnant forest stands along the prairie-forest ecotone, Minnesota, USA [J]. Plant Ecology, **129**: 121-124.

Fortin, M.J. 1994. Edge detection algorithms for two-dimensional ecological data [J]. Ecology, **75**: 956-965.

Guo Qing-xi. 2001. Scientific significance of the forest vegetation ecotone between Daxing'an Mountains and Xiaoxing'an Mountains to study of global climate change [J]. Journal of Forestry Research, **12**(2): 93-96.

Liu S.E. 1985. Liu Shene papers collection [M]. Beijing: Science Press. 179-228 (in Chinese).

Stohlgern, T.J., Bachand, R.R. 1997. Lodgepole pine (*Pinus contorta*) ecotones in Rocky Mountain National Park, Colorado, USA [J]. Ecology, **78**: 632-641.

Tsuchiya, T., Shinozuka, A., Ikusima, I. 1993. Population dynamics, productivity and biomass allocation of *Zizania latifolia* in an aquatic-terrestrial ecotone [J]. Ecological Research, **8**: 193-198.

Xu Wenduo, Liu Guangtian, Duan Peishan, Zou Chunjing. 1998. Study on Picea mongolica forest ecosystem in Baiyinaobao Natural Preserve, Inner Mongolia [M]. Beijing: Chinese Forestry Press. (in Chinese).

Xu Wenduo, Zou Chunjing. 1998. Sandy forest ecosystem of China [M]. Beijing: Chinese Forestry Press. (in Chinese).

Xu Wenduo. 1993. The relation between distribution of edificator and cornpanion in zonal vegetation and water-temperature condition in Northeast China [J]. Chinese Journal of Botany, **25**(3): 264-274 (in Chinese).

Zou Chunjing, Han Shijie and Xu Wenduo. 1999. Application of ecological field theory to regeneration of *Picea mongolica* population [J]. Acta Ecologica Sinica, **19**(1): 50-54 (in Chinese).

Zou Chunjing, Han Shijie, Zhang Junhui *et al.* 2000. Characteristics and dynamics of sandy natural forests in sandy forest steppe ecotone in northern area of China. Journal of Forestry Research, **11**(3): 161-166.